TOTAL MAXIMUM DAILY LOAD (TMDL) DEVELOPMENT

For FECAL COLIFORM in the

DRY CREEK WATERSHED

(HUC 03150202)

Perry and Dallas Counties, Alabama

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1.0 EXECUTIVE SUMMARY: CROOKED CREEK

Section 303(d) of the Clean Water Act and EPA's Water Quality Planning and Management Regulations (40 CFR Part 130) requires states to identify waterbodies which are not meeting their designated use and to determine the Total Maximum Daily Load (TMDL) for pollutants causing the use impairment. TMDLs are the sum of individual wasteload allocations for point sources (WLAs), load allocations (LAs) for nonpoint sources including natural background levels, and a margin of safety (MOS).

The State of Alabama has identified Crooked Creek on the 1998 303(d) list as not supporting its designated use of Fish and Wildlife for pathogens. Crooked Creek in Perry and Dallas Counties lies within the Cahaba River basin, hydrologic unit 03150202. Crooked Creek is a tributary to the Cahaba River; its watershed is predominantly agricultural with little urban or developed area and is approximately 5,329 acres (8.3 sq. mi.).

Fecal coliform is used as the indicator for pathogen TMDLs in Alabama. A geometric mean of 200 colonies/100mL was established as the target for this TMDL. Water quality data collected on Crooked Creek in 1996 was used for listing the stream from its headwaters to Cahaba River as not supporting its designated use on Alabama's 1998 303(d) list.

The Nonpoint Source Model (NPSM) was chosen as the model to complete this TMDL. The Watershed Characterization System (WCS), a geographic information system (GIS) interface, was used to display, analyze and compile spatial and attribute data. Crooked Creek was delineated into a single subwatershed based on a Reach File 3 (RF3) stream coverage and a Digital Elevation Model (DEM) of the area. The farthest downstream point of the delineation was the water quality sampling station CRK-5. A continuous simulation period of 10 years (1/1/88 – 12/31/98) was used.

Loads from existing sources contributing to nonpoint sources were combined to form three load groups. The first group, runoff from all lands, contributed 6.11×10^9 counts/30 days and consisted of deposits from grazing animals, an estimate of loading based on the deer population (wildlife) and loads from land applied manure. The second group, leaking septic systems, contained only information related to septic systems and contributed 6.67×10^9 counts/30 days. The final group, miscellaneous sources, consisting of livestock with stream access and an estimate of unknown instream sources and illicit discharges contributed 2.56×10^{11} counts/30 days to the total existing load. There were no contributing point sources for this TMDL in this watershed.

An allocation scenario that predicts compliance with instream water quality standards requires individual reductions from runoff from all lands (29%), leaking septic systems (60%) and miscellaneous sources was 95%. The components for the resulting TMDL are summarized below.

Watershed	WLA cnts/30 days	LA cnts/30 days	MOS	TMDL cnts/30 days
Dry Creek	0×10^{0}	1.98×10^{10}	Implicit	1.98×10^{10}

Using a 10-year simulation period offered the opportunity to observe seasonal dependency. Loading rates were varied monthly in the NPSM. The varying rates were based on reports obtained from the WCS and monthly application rates of animal manure to cropland and pastureland.

An implicit margin of safety was incorporated using conservative modeling techniques. Conservative assumptions included; use of the most stringent water quality standard year round, loads form leaking septic systems are assumed to be directly connected to the stream, nonpoint loads area assumed to have direct paths to streams.

Fecal coliform loads for Crooked Creek are attributed to sources modeled as both point and nonpoint sources. This combination of sources makes it difficult to predict when the critical peak will occur; therefore, a long-term analysis was employed. Use of a long-term analysis allowed the prediction of fecal loads for many rainfall scenarios and therefore, a representative critical peak. For Crooked Creek, the highest violations of the 30-day geometric mean occurred on 9/15/96. The resulting critical period was 8/17/96 to 9/15/96.

2.0 TMDL: CROOKED CREEK

2.1 Introduction

2.1.1 The TMDL Process

Section 303(d) of the Clean Water Act and EPA's Water Quality Planning and Management Regulations (40 CFR Part 130) requires states to identify waterbodies which are not meeting their designated use and to determine the Total Maximum Daily Load (TMDL) for pollutants causing the use impairment. The TMDL process establishes the allowable loadings of pollutants for a waterbody based on the relationship between the pollution sources and instream water quality conditions, so that states can establish water quality based controls to reduce pollution and restore and maintain the quality of their water resources (USEPA 1991).

TMDLs are the sum of individual wasteload allocations for point sources (WLAs), load allocations (LAs) for nonpoint sources including natural background levels, and a margin of safety (MOS). The margin of safety can be included either explicitly or implicitly and accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody. If the MOS is accounted for explicitly, a portion of the total TMDL is specified; in most cases, the MOS is implicit and accounted for with conservative modeling techniques. A TMDL is denoted by the equation:

$$\text{TMDL} = \Sigma\text{WLAs} + \Sigma\text{LAs} + \text{MOS}$$

TMDLs can be expressed in terms of either mass per time, toxicity, or other appropriate measure. For bacteria, TMDLs are expressed in terms of organism counts (or resulting concentration), in accordance with 40 CFR Part 130.2(1).

2.1.2 Watershed Description

The State of Alabama has identified Crooked Creek on the 1998 303(d) list as not supporting its designated use for Fish and Wildlife for pathogens. Crooked Creek in Perry and Dallas, Counties lies within the Cahaba River basin, hydrologic unit 03150202 (Figure 1). Crooked Creek is a tributary to Cahaba River; its watershed is predominantly agricultural with little urban or developed area and is approximately 5,329 acres (8.3 sq. mi.). Table 1 provides a breakdown of land use in acres, square miles and percent of total.

Table 1. Crooked Creek Watershed Land Use Distribution

Landuse	Acres	Square Miles	Percent of Total Watershed
Cropland	1,793	2.8	33.6%
Pastureland	1,905	3.0	35.7%
Forest Land	1,631	2.5	30.6%
Urban Land	1	0.0	0.0%
Total	**5,330**	**8.3**	**100.0%**

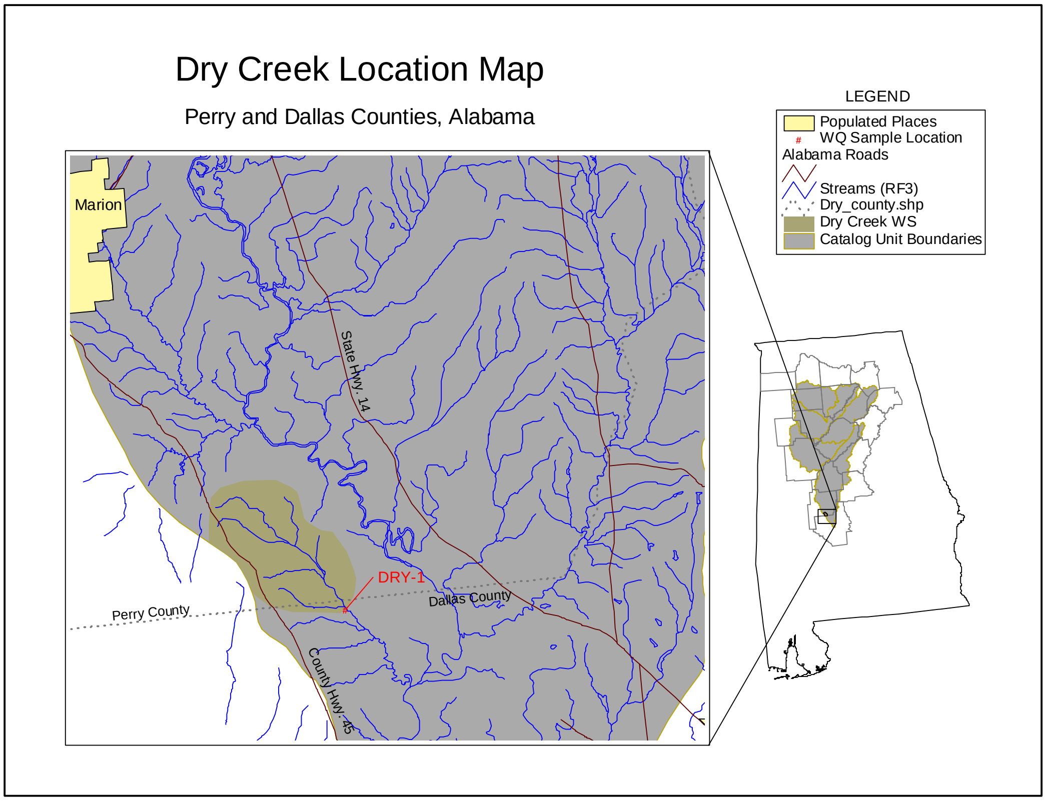

Figure 1. Crooked Creek watershed location map.

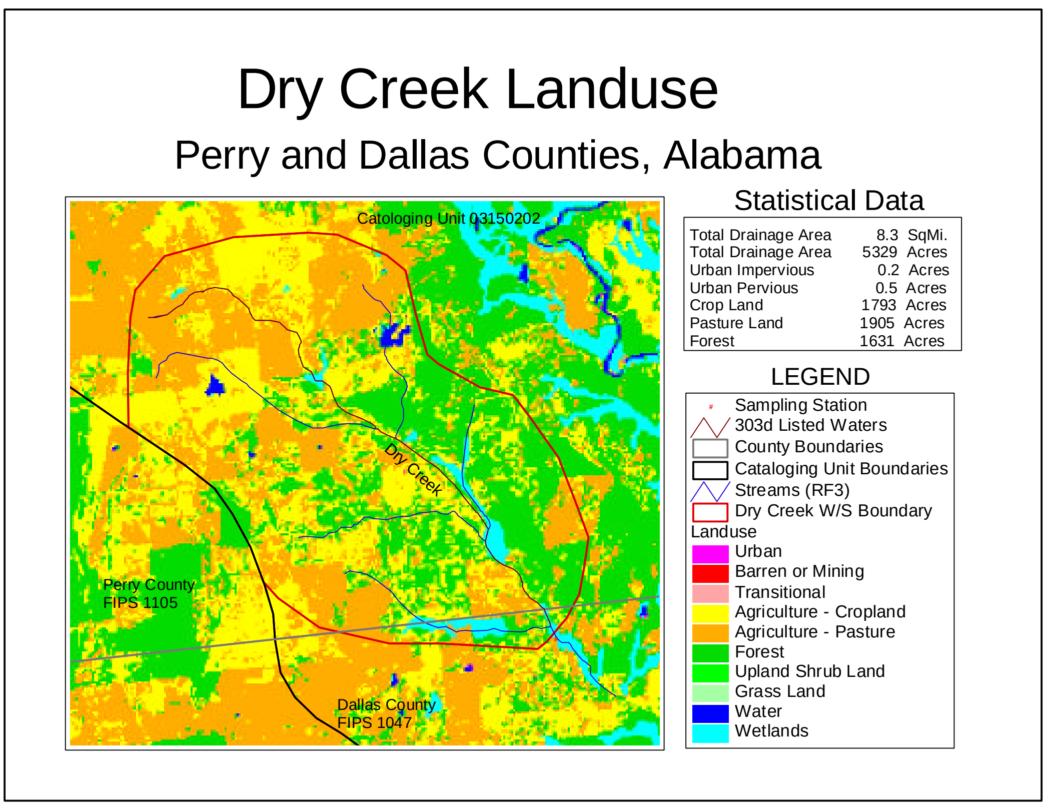

Figure 2. Crooked Creek land use distribution and statistics.

2.1.3 Designated Use of the 303(d) Stream

The use classification for Crooked Creek is Fish and Wildlife which is described in ADEM Admin. Code R. 335-6-10-.09(5)(a), (b), (c), and (d)..

(a). Best usage of waters:
Fishing, propagation of fish, aquatic life, and wildlife, and any other usage except for swimming and water-contact sports or as a source of water supply for drinking or food processing purposes.

(b). Conditions related to best usage:
The waters will be suitable for fish, aquatic life and wildlife propagation. The quality of salt and estuarine waters to which this classification is assigned will also be suitable for the propagation of shrimp and crabs.

(c). Other usage of waters:
It is recognized that the waters may be used for incidental water contact and recreation during June through September, except that water contact is strongly discouraged in the vicinity of discharges or other conditions beyond the control of the Department or the Alabama Department of Public Health.

(d). Conditions related to other usage:
The waters, under proper sanitary supervision by the controlling health authorities, will meet accepted standards of water quality for outdoor swimming places and will be considered satisfactory for swimming and other whole body water-contact sports.

2.2 TMDL Indicators and Numeric Targets

Fecal coliform is used as the indicator for pathogen TMDLs in Alabama. Criteria for acceptable bacteria levels for the Fish and Wildlife use classification are presented in ADEM Admin. Code R. 335-6-10-.09(5)(e)7.(i) and (ii).

i. Bacteria of the fecal coliform group shall not exceed a geometric mean of 1,000 colonies/100mL; nor exceed a maximum of 2,000 colonies/100mL in any sample. The geometric mean shall be calculated from no less than five samples collected at a given station over a 30-day period at intervals not less than 24 hours.

ii. For incidental water contact and recreation during June through September, the bacterial quality of water is acceptable when a sanitary survey by the controlling health authorities reveals no source of dangerous pollution and when the geometric mean fecal coliform organism density does not exceed 100 colonies/100mL in coastal waters and 200 colonies/100mL in other waters. The geometric mean shall be calculated from no less than five samples collected at a given station over a 30-day period at intervals not less than 24 hours. When the geometric mean fecal coliform organism density exceeds these levels, the bacterial water quality shall be considered acceptable only if a second detailed sanitary survey and evaluation discloses no significant public health risk in the use of the waters. Waters in the immediate vicinity of discharges of sewage or other wastes likely to contain bacteria harmful to humans, regardless of the degree of treatment afforded these wastes, are not acceptable of swimming or other whole body water-contact sports.

Incidental water contact and recreation is the most stringent of the use classifications. The geometric mean standard of 200 counts/100mL was used as the target level for TMDL development.

2.3 Water Quality Assessment

Water quality data collected on Crooked Creek in 1996 was used for listing the stream on Alabama's 1998 303(d) list and is presented in Table 2. Although insufficient data were collected to calculate 30-day geometric mean values, individual samples exceeded the maximum daily value of 2000 counts/100mL. Therefore, Crooked Creek, from its headwaters to County Road 201, was listed as not supporting its designated use and was scheduled for TMDL evaluation. The water quality sampling station for Crooked Creek, CRK-5 is located on Crooked Creek N 32.485, W 87.2063. The station location is shown on Figure 1.

Table 2 . Water quality sampling data collected at CRK-5 for Crooked Creek.

Station	Date	F.C. counts/100ml	Station	Date	F.C. counts/100ml
Dry-1996	2/29/96	7,400	Dry-1996	8/21/96	370
Dry-1996	3/27/96	2,700	Dry-1996	9/25/96	540
Dry-1996	5/23/96	20	Dry-1996	10/23/96	410
Dry-1996	6/19/96	1,000	Dry-1996	12/18/96	40,000

2.4 Source Assessment

2.4.1 Background

Wildlife, including deer, raccoons, wild turkeys, waterfowl, etc., is considered significant contributors to background concentrations of fecal coliform. Due to the lack of population estimates for raccoons, waterfowl and other wildlife that may inhabit the watershed, the deer population was used to estimate the fecal coliform load from wildlife. Based on discussions with ADEM, the population of deer in the watershed was estimated at 45 deer/sq. mile. The fecal coliform loading rate from deer was estimated by linear interpolation using the rates for other animals, such as turkey and cattle, reported in Metcalf and Eddy (1991). The interpolation was based on animal weight and fecal coliform production rate. The resulting loading rate from deer was estimated at 5.0×10^{8} counts/animal/day.

2.4.2 Point Source Assessment

A point source can be defined as any discernable, confined, and discrete conveyance from which pollutants are or may be discharged to surface waters. Point source discharges of industrial wastewater, treated sanitary wastewater, storm water associated with industrial activity, or storm water from municipal storm sewer systems that serve over 100,000 people must be authorized by National Pollutant Discharge Elimination System (NPDES) permits. Permitted facilities impacting the impaired stream are entered as point sources having constant flow and concentration based on design flow and permit limits for fecal coliform bacteria. NPDES permitted facilities are the only contributions to the wasteload allocation (WLA) component of the TMDL. There are no NPDES permitted facilities located within the Crooked Creek watershed. All future NPDES facilities will be required to meet end-of-pipe criteria equivalent to the water quality standard for fecal coliform bacteria of 200 counts/100mL.

2.4.3 Nonpoint Source Assessment

Nonpoint sources of fecal coliform bacteria are diffuse sources that cannot be identified as entering the waterbody at a single location. These sources generally involve land activities that contribute fecal coliform bacteria to streams during rainfall runoff events. Fecal coliform loading rates for various livestock were estimated to be $1.06\text{x}10^{11}$ counts/day/beef cow, $1.04\text{x}10^{11}$ counts/day/dairy cow, $1.24\text{x}10^{10}$ counts/day/hog, $1.38\text{x}10^{8}$ counts/day/chicken and $4.18\text{x}10^{8}$ counts/day/horse (NCSU 1994). All sources considered to be nonpoint sources contribute to the load allocation (LA) portion of the TMDL. Typical nonpoint sources of fecal coliform bacteria include:

- Septic Systems
- Livestock in streams
- Land application of manure
- Wildlife
- Urban Runoff
- Pastures

Septic Systems and Urban Runoff

Leaking septic systems were modeled as point sources having a constant flow and concentration. The number of people in the Crooked Creek watershed on septic systems was estimated using 1997 U.S. Census Bureau county data shown in Table 3. Using best professional judgment and local information, it was assumed that 10 percent of the total septic systems in the watershed would leak or fail. Literature values were used to estimate the loadings from failing septic systems in the watershed using a representative effluent flow and concentration. Horsley and Witten (1996) estimate septic effluent concentrations as 10^{6}counts/100mL with an average daily discharge of 70 gallons/person-day. Using this information, the load from failing septic systems was estimated to be 2.67×10^{9} counts/30 days. This value is a conservative estimate of the load as it does not account for die-off or attenuation of loadings of fecal coliform from failing septic systems to the stream. Additionally, stormwater runoff from rural areas can contribute to fecal coliform nonpoint source loads by delivering litter and the waste of domestic pets and wildlife to the stream.

Table 3. Estimated Population on Septic Systems.

Watershed	Estimate of Individuals on Septic Systems
Dry Creek	84

Livestock in Streams and Unknown Sources

Livestock often have access to small streams in their grazing areas. Loads attributed to livestock in streams were included as an hourly point source of constant flow and concentration. Initial loads were based on the beef cattle population in the watershed and literature values for fecal coliform bacteria produced daily per beef cow. In computing the load, it was assumed 50 percent of the beef cattle had access to the streams and of those, 25 percent deposit wastes in or near the stream bank. Estimates of beef cattle in the watershed as determined from county agricultural census data (USDA 1997) are shown in

Table 4. During the water quality calibration, this load can be adjusted to better match observed low flow concentrations. The component, livestock in streams, is defined as a nonpoint source but was modeled as a point source because of model limitations. Livestock contributions were then included correctly in the load allocation (LA) portion of the TMDL.

Land Application of Animal Manure

Beef cattle are the predominant livestock in the watershed. Estimates of the numbers of livestock in the watershed are from U.S. Department of Agriculture (USDA) National Agriculture Statistics System (USDA 1997) and are shown in

Table 4. ADEM requires a general NPDES permit for all concentrated animal feeding operations (CAFOs) in excess of 1000 animal units and for poultry operations in excess of 125,000 birds. The general NPDES permit for CAFOs is a ‘no discharge’ permit except during the 25-year, 24-hour storm event, and then the CAFO facility can discharge only process overflow wastewater to the stream. Based on the number of cattle in the watershed, CAFOs could be causing or contributing to the impairment of Dry Creek as indicated by the 303(d) listing.

Agricultural operations with confined animals generally stack or hold their manure until it can be applied to cropland or pasture land. Estimated application rates used in the model vary monthly and by type of animal operation and are listed in Table 5

Table 4. Estimated number of agricultural animals in the Crooked Creek watershed based upon the agricultural census data (USDA 1997).

Watershed	Estimated Number of Animals
Beef Cattle	308
Poultry	0
Swine	4
Dairy Cattle	21

Table 5. Estimated land application rates for confined animal manure in Crooked Creek (NRCS 2000).

	% Of One Years Confined Manure Applied In Each Month												% Applied to	
Operation	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Pasture**	**Crop Land**
Swine	2	2	10	17	10	6	6	9	17	13	6	2	90	10
Beef	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	100	0
Dairy	4	4	9	14	9	7	7	9	14	12	7	4	50	50
Broiler	1	5	10	14	10	10	10	10	10	14	5	1	70	30
Layer	1	1	10	19	10	10	9	10	10	14	5	1	90	10

Wildlife

Wildlife deposit waste containing fecal coliform bacteria onto the land where it can be transported during a rainfall runoff event to nearby streams. Fecal coliform contributions from wildlife were represented in the model based on deer population. It was assumed that deer are uniformly distributed to forest land, pasture land, crop land and wetland areas at a density based on local information. Fecal coliform loading rates due to deer were estimated (refer to Section 2.4.1 for discussion) to be 5.0×10^8 counts/animal/day with an assumed population of 45 deer/sq.mile. Using this rate and the assumption of equally distributed population of deer between forest and agricultural land uses, the fecal coliform load to the land surface (the background load) was calculated.

2.5 Linking the Sources to the Indicators and Targets

Establishing the relationship between instream water quality and sources of fecal coliform, the pathogen indicator, is an important component of the TMDL. It provides the relative contribution of the sources, as well as a predictive examination of water quality resulting from changes in these source contributions.

3.5.1 Model Selection

The model selected for this TMDL needed to meet several objectives. The first objective was to simulate the time varying behavior of the deposition and transport of fecal coliform bacteria from the land surface to receiving water bodies. The second was to use a continuous simulation period to identify the critical condition from which to develop the TMDL. Having the ability to use a continuous simulation period while varying the monthly loading rates; provided the means to evaluate seasonal effects on the production and fate of fecal coliform bacteria.

The Nonpoint Source Model (NPSM) is a dynamic watershed model capable of; simulating nonpoint source runoff and associated pollutant loads, accounting for point source discharges, and performing flow and water quality routing through stream reaches.

It is based on the Hydrologic Simulation Program – FORTRAN (HSPF) and was chosen as the model to complete this TMDL.

The Watershed Characterization System (WCS), a geographic information system (GIS) interface, was used to display, analyze and compile spatial and attribute data. Available data sources included landuse category, point source discharges, soil type and characteristics, population data (human and livestock), digital elevation data, stream characteristics, precipitation and flow data. Results from these analyses provided input to loading spreadsheets developed by Tetra Tech, Inc.; output from the spreadsheets included fecal coliform loading rates from surface runoff and from direct sources including leaking septic systems and livestock with stream access. This output was used to support and estimate the initial water quality model parameters.

3.5.2 Model Setup

Crooked Creek was delineated into a single subwatershed based on a Reach File 3 (RF3) stream coverage and a Digital Elevation Model (DEM) of the area. The farthest downstream point of the delineation was the water quality sampling station CRK-5. Local meteorological data and local watershed and stream characteristics were used. Landuse in the watershed was characterized based on Multi-Resolution Land Characteristics (MRLC) digital images dated 1990-1993. A continuous simulation period of 10 years (1/1/88 - 12/31/98) was used to analyze the TMDL as this incorporates a wide range of meteorological events for evaluating the worst-case scenario. This long time period also allows the TMDL to be based on a range of seasonal conditions.

2.5.3 Calibration

The NPSM is driven by precipitation; therefore, it is important to calibrate hydrologic parameters prior to attempting a calibration for water quality. Long-term hourly precipitation data were obtained from the National Oceanic and Atmospheric Association (NOAA) and were used as input in the model for stream flow simulation. The predicted stream flow was then compared to the historic stream flow data from a continuous stream gage. Hydrologic parameters of infiltration, upper and lower zone storage, groundwater storage and recession, interflow, and evapotranspiration, were used to represent the hydrologic cycle and were adjusted until the simulated and observed hydrographs matched. The hydrologic calibration is the foundation of the water quality model.

Water quality model calibration follows. The model parameters were adjusted until acceptable agreement was achieved between simulated fecal loads and observed data from the water quality station. To calibrate the model, several parameters were adjusted including rates of fecal coliform bacteria accumulation, wash-off rates, maximum storage of fecal coliform bacteria and contributions from direct sources. Water quality data were often limited but by matching the trends in simulated and observed concentrations resulting from peak and base flows, the model can be a reasonable predictor of instream water quality and be considered calibrated. The inability to accurately simulate specific observed data points can sometimes be attributed to differences in rainfall at the meteorological gage and the watershed as well as illicit point discharges.

Hydrologic Calibration

A continuous flow gage was not located in the Crooked Creek watershed; therefore, a hydrologic calibration was performed at a nearby gage (USGS 0240250 Sipsey Fork). The hydrologic parameters determined were then used for Crooked Creek. The period from 1/1/89 to 12/31/89 was used as the calibration period for the hydrologic parameters as this was the extent of flow data and meteorological data were not available past 1998. The Huntsville, Alabama weather station provided the meteorological data. Relative fit of the modeled flow compared to the recorded flow is shown in Figure 3.

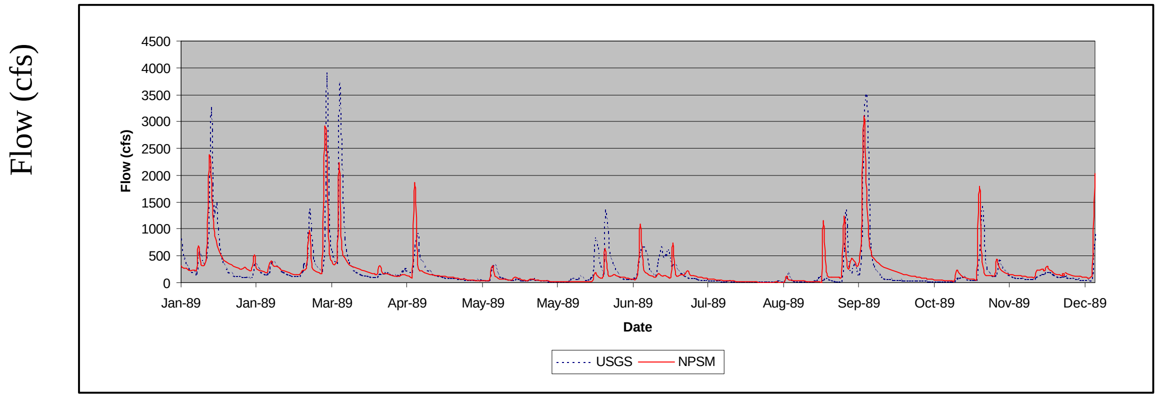

Figure 3. Daily modeled flow versus recorded data from USGS 0240250 Sipsey Fork.

Water Quality Calibration

Water quality samples collected at CRK-5 from 2/29/96 to 12/18/96 were compared to simulated concentrations in the water quality calibration. Appropriate model parameters were adjusted to obtain acceptable agreement between average daily simulated concentrations and observed data collected at station CRK-5. Results shown in Figure 4 indicate that the model adequately simulated the response of fecal coliform bacteria during storm and low flow events.

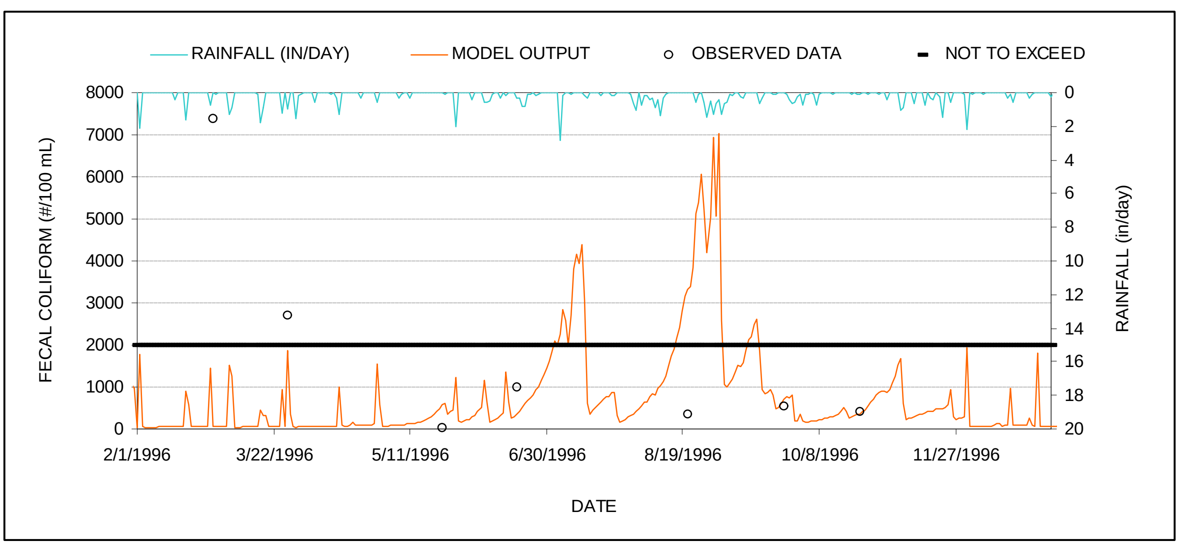

Figure 4. Simulated versus observed coliform bacteria concentration for Crooked Creek (Station CRK-5).

2.5.4 Results from Water Quality Modeling

Source loading rates representing existing conditions are shown in Table 6. In reviewing this table, it should be understood that *runoff from all lands* includes: deposits from grazing animals, an estimate of loading based on the deer population, an estimate from urban areas, and loads from land applied manure. *Leaking septic systems* contains only information related to septic systems. *Miscellaneous sources* include two components: livestock with stream access as well as an estimate of unknown instream sources and illicit discharges. The model results in Table 6 indicate that animal access to streams and unknown or illicit discharges have the most significant impact on fecal coliform bacteria loads. The model also predicts impacts from stormwater runoff. Loads from leaking septic systems and miscellaneous sources impact instream water quality only during periods of low flow. The existing fecal coliform load for Crooked Creek was determined in the following manner:

- The calibrated model was run for a time that included the critical condition.
- The daily fecal coliform load from all sources was summed for the 30 day critical period. This value represents the existing load.

Table 6. Summary of predicted existing coliform loads in the Dry Creek watershed.

Watershed	Runoff From All Lands	Leaking Septic Systems	Miscellaneous Sources
	Counts/30 Days[1]	Counts/30 Days	Counts/30 Days[2]
Dry Creek	6.11×10^{9}	6.67×10^{9}	2.56×10^{11}

1 Includes grazing animals, deer population, land-applied manure, and urban runoff.
2 Includes livestock with stream access and illicit discharges.

2.6 Allocation

2.6.1 Total Maximum Daily Load (TMDL)

Once the model was calibrated for water quality, load reductions were applied until the simulated 30-day geometric mean of the fecal coliform bacteria counts did not exceed the water quality geometric mean standard of 200 counts/100mL. The wasteload allocation (WLA) portion of the TMDL includes any NPDES permitted facilities. The load allocation (LA) portion includes coliform from grazing animals, animals with access to streams, urban runoff and illicit discharges, leaking septic systems and runoff from land applied animal manure.

An allocation scenario that predicts compliance with instream water quality standards requires reductions in the individual categories shown in Table 7. Final allocated values for the TMDL including wasteload allocation, load allocation and margin of safety are shown in Table 8.

Table 7. Predicted loads and percent reductions needed to meet water quality standards for Crooked Creek.

	Runoff From All Lands	**Leaking Septic Systems**	**Miscellaneous Sources**
	Counts/30 Days	**Counts/30 Days**	**Counts/30 Days**
Dry Creek	4.32×10^{9}	2.67×10^{9}	1.28×10^{10}
% Reduction	29%	60%	95%

Table 8. TMDL components for Crooked Creek.

Watershed	**WLA**	**LA**	**MOS**	**TMDL**
	cnts/30 days	**cnts/30 days**		**cnts/30 days**
Dry Creek	0×10^{0}	1.98×10^{10}	Implicit	1.98×10^{10}

2.6.2 Seasonal Variation

A 10-year simulation period was used to assess loads and their affect on water quality; this period included seasonal variation. In addition, loading rates were varied monthly in the model. These rates were based on reports obtained from the Watershed Characterization System and on monthly application rates of animal manure to cropland and pastureland.

2.6.3 Margin of Safety

An implicit margin of safety was incorporated in this TMDL using conservative modeling techniques. These are:

- The TMDL target was developed against the most stringent water quality standard.
- Loads from leaking and failing septic systems were treated as point sources with a constant concentration and flow.
- All landuses were modeled as if they were directly connected to the stream.

2.6.4 Critical Conditions

The critical condition for nonpoint source fecal coliform loading is an extended dry period followed by a rainfall runoff event. During the dry weather period, fecal coliform bacteria builds up on the land surface, and is transported to the stream by rainfall. The critical condition for point source loading occurs during periods of low stream flow when dilution is minimized. Both conditions are simulated in the water quality model.

The 10-year period from 1/1/89 to 12/31/98 was used to simulate a continuous 30-day geometric mean distribution to compare to the target. This 10 year period contained a range of hydrological conditions that included both low and high stream flows from which critical conditions were identified and used to derive the TMDL value.

The 10-year simulated geometric mean concentrations for existing conditions are presented in Figure 5. The 30-day critical period in the model is the period preceding the largest simulated violations of the geometric mean standard (USEPA 1991). The critical period excludes periods of model instability, when the simulated stream flow approaches zero and causes concentrations to become negative, or abnormal weather conditions such as floods or drought. Meeting water quality standards during the critical period ensures that water quality standards can be achieved throughout the simulation period. For Crooked Creek, the highest violations of the 30-day geometric mean occurred on 9/15/96. The critical period becomes 8/17/96 to 9/15/96.

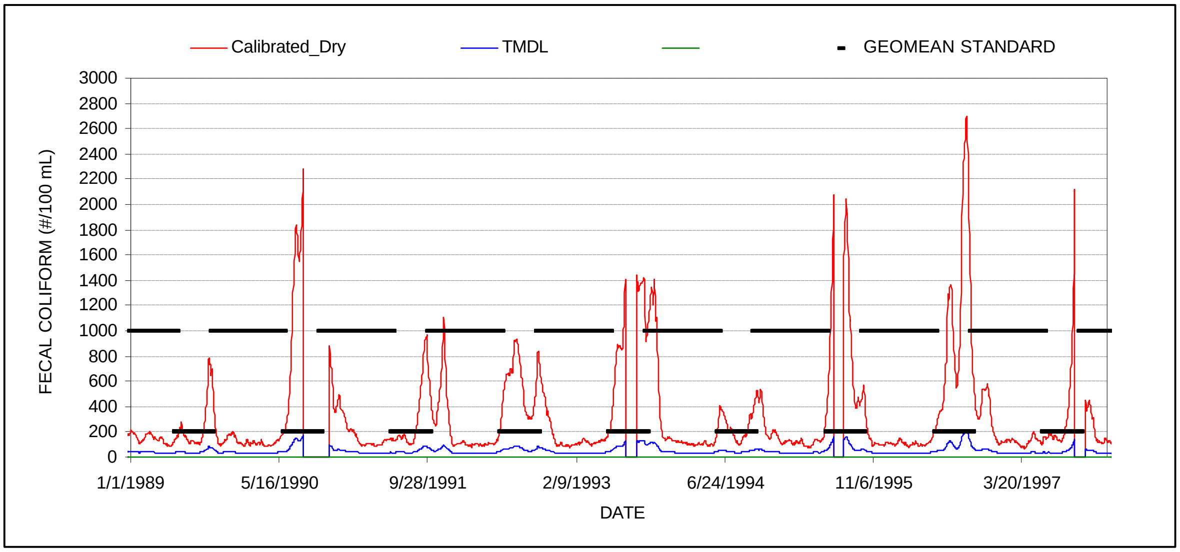

Figure 5. Geometric mean plot for Crooked Creek.

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